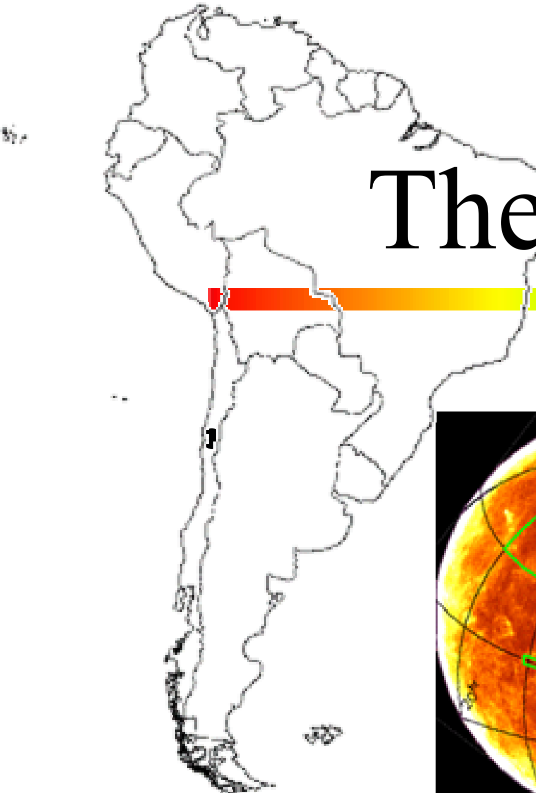
The Science Case for the Dark Energy Survey

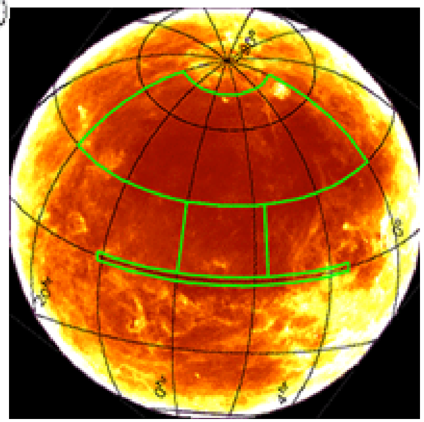
James Annis

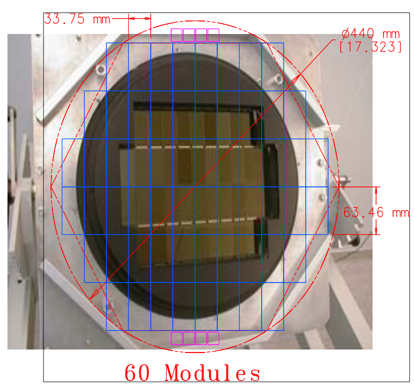
For the DES Collaboration

The Dark Energy Survey

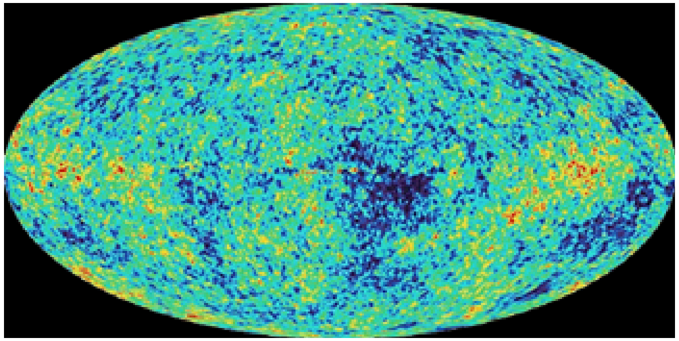


- We propose to make precision measurements of Dark Energy
  - Cluster counting, weak lensing and supernovae
  - Independent measurements
- by mapping the cosmological density field to z=1
  - Measuring 300 million galaxies
  - Spread over 5000 sq-degrees
- using new instrumentation of our own design.
  - 500 Megapixel camera
  - 2.1 degree field of view corrector
  - Install on the existing CTIO 4m

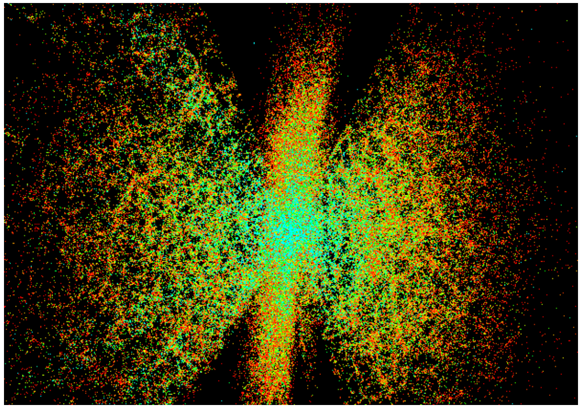




Cosmology in 2004



WMAP measures the CMB radiation density field at z=1000



Sloan Digital Sky Survey measures the galaxy density field at z < 0.3

Combine to measure parameters of cosmology to 10%.

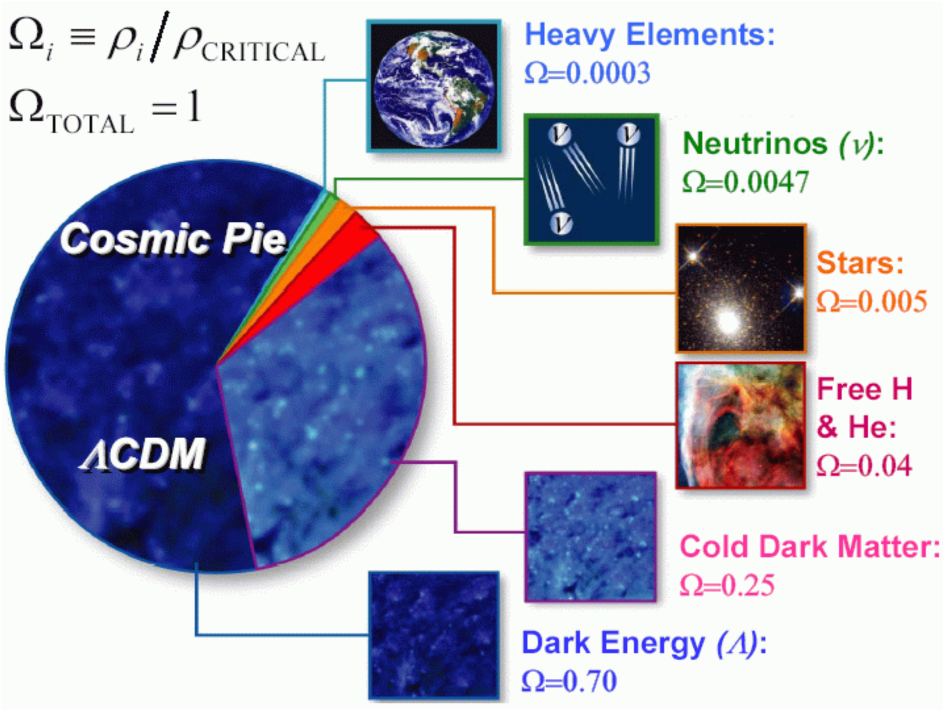
We enter the era of precision cosmology.

– Confirms dark energy (!)

2003 Science breakthrough of the year

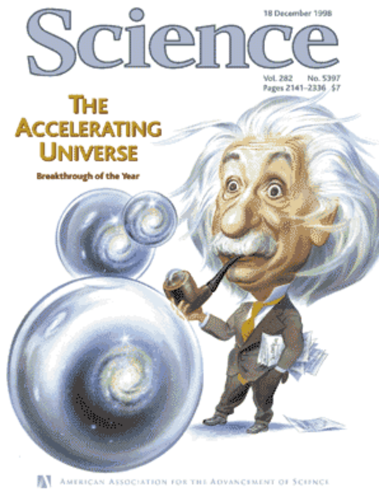
The Big Problems: Dark Energy and Dark Matter

The confirmation of Dark Energy points to major holes in our understanding of fundamental physics



- Dark energy?

  Who ordered that? (said Rabi about muons)
- Dark energy is the dominant constituent of the Universe
- Dark matter is next



95% of the Universe is in forms unknown to us

1998 Science breakthrough of the year

Dark Energy

1. The Cosmological Constant Problem

   Particle physics theory currently provides no understanding of why the vacuum energy density is so small: $\rho_{DE}^{(\mathrm{Theory})}/\rho_{DE}^{(\mathrm{obs})} = 10^{120}$

2. The Cosmic Coincidence Problem

   Theory provides no understanding of why the Dark Energy density is just now comparable to the matter density.

3. What is it?

   Is dark energy the vacuum energy? a new, ultra-light particle? a breakdown of General Relativity on large scales? Evidence for extra dimensions?

The nature of the Dark Energy is one of the outstanding unsolved problems of fundamental physics.

Progress requires more precise probes of Dark Energy.

Measuring Dark Energy

- One measures dark energy through how it affects the universe expansion rate, H(z):

  $H^2(z) = H^2_0 \; [\, \Omega_M \,(1+z)^{\,3} + \Omega_R \,(1+z)^{\,4} + \Omega_{DE} \,(1+z)^{\,3\,(1+w)} \,]$

  matter radiation dark energy

- Note the parameter w, which describes the evolution of the density of dark energy with redshift. A cosmological constant has $w = -1$.

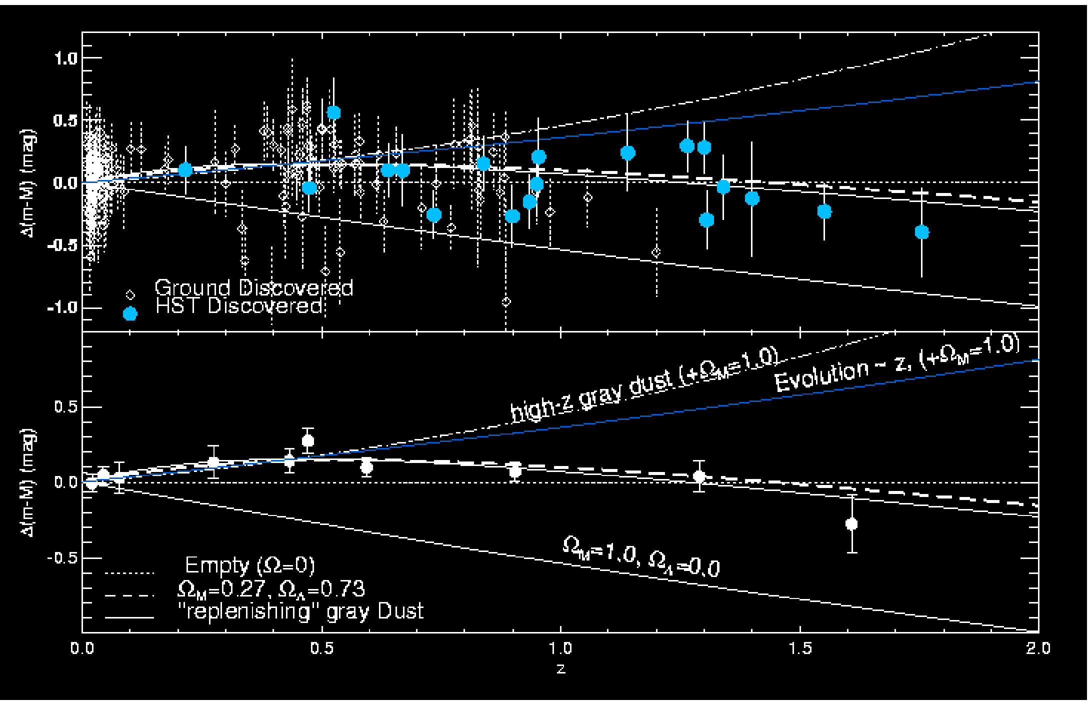
  w is currently constrained to ~20% by WMAP, SDSS, and supernovae

- Measurements are usually integrals over H(z) $r(z) = \int dz/H(z)$
- Standard Candles (e.g., supernova) measure $d_L(z) = (1+z)\, r(z)$
- Standard Rulers measure $d_a(z) = (1+z)^{-1}\, r(z)$
- Volume Markers measure $dV/dzd\Omega = r^2(z)/H(z)$
- The rate of growth of structure is a more complicated function of H(z)

DES Dark Energy Measurements

- New Probes of Dark Energy
  - Galaxy Cluster counting
    - 20,000 clusters to z=1 with $M > 2 \times 10^{14} M_{\odot}$
  - Weak lensing
    - 300 million galaxies with shape measurements
  - Spatial clustering of galaxies
    - 300 million galaxies
- Standard Probes of Dark Energy
  - Type 1a Supernovae distances
    - 2000 supernovae

Supernova



- Type 1a Supernovae magnitudes and redshifts provide a direct means to probe dark energy
  - Standard candles

DES will make the next logical step in this program:

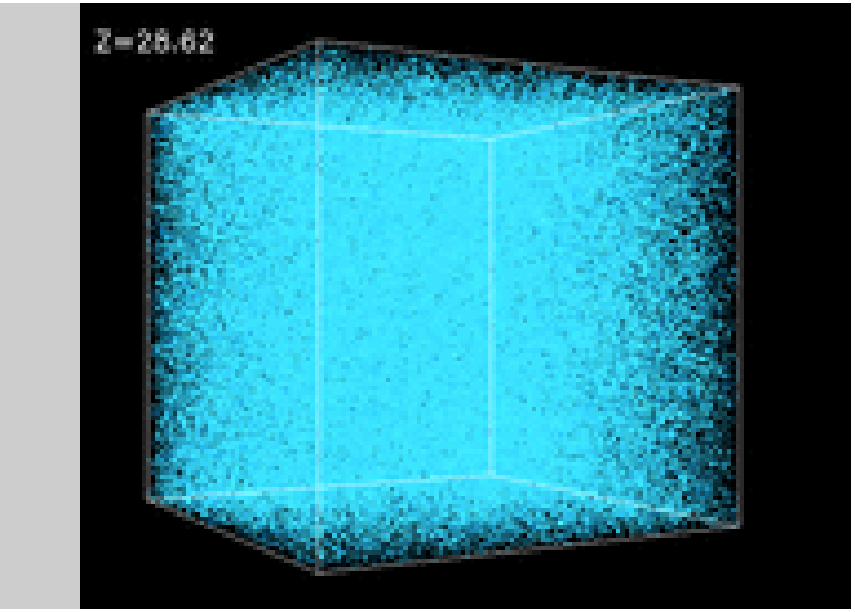
- Image 40 sq-degree repeatedly
- 2000 supernovae at z < 0.8
- Well measured light curves

Current projects: SCP, Essence, CFHLS

Proposed projects: SDSS, PanStarrs, LSST, SNAP

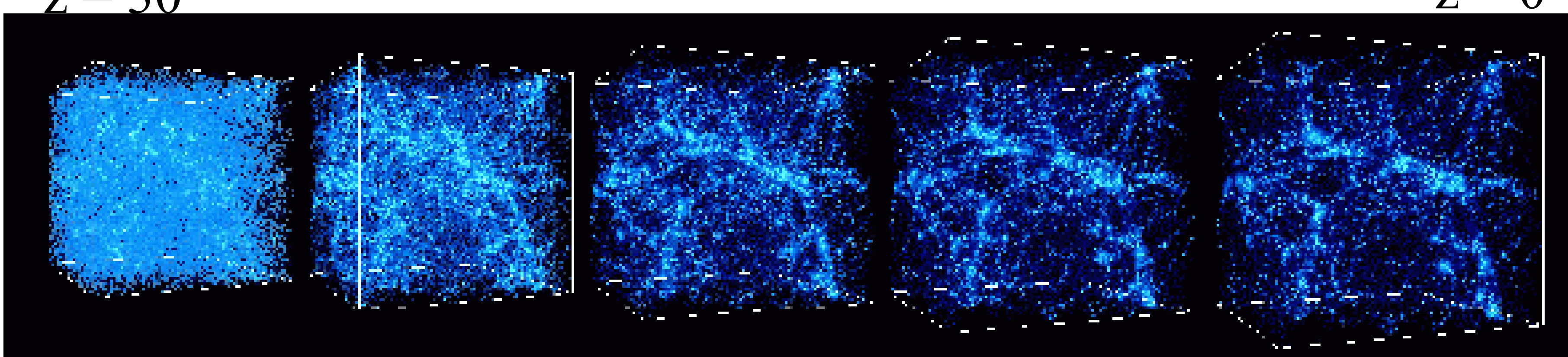
2000, 2005, DES, 2010, 2015, 2020

New Probes of Dark Energy

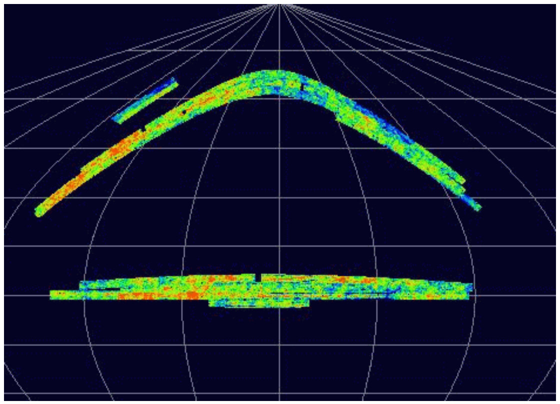


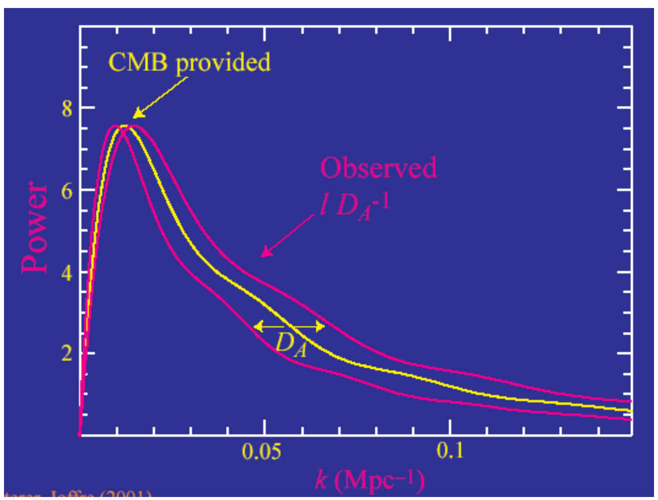
- Rely on mapping the cosmological density field
- Up to the decoupling of the radiation, the evolution depends on the interactions of the matter and radiation fields - **‘CMB physics’**
- After decoupling, the evolution depends only on the cosmology - **‘large-scale structure in the linear regime’**.
- Eventually the evolution becomes non-linear and complex structures like galaxies and clusters form - **‘non-linear structure formation’**.

z = 30 z = 0



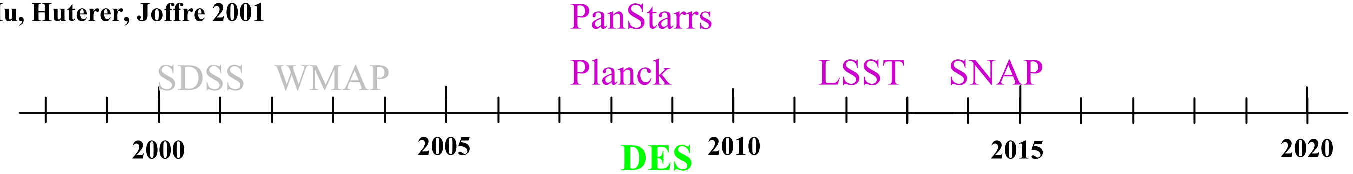
Spatial Clustering of Galaxies

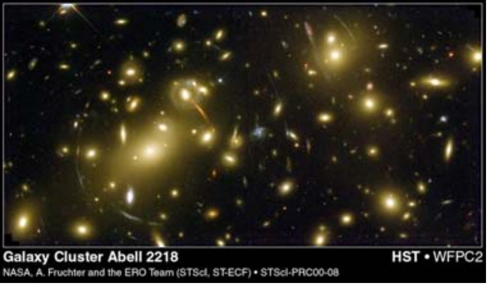




Cooray, Hu, Huterer, Joffre 2001

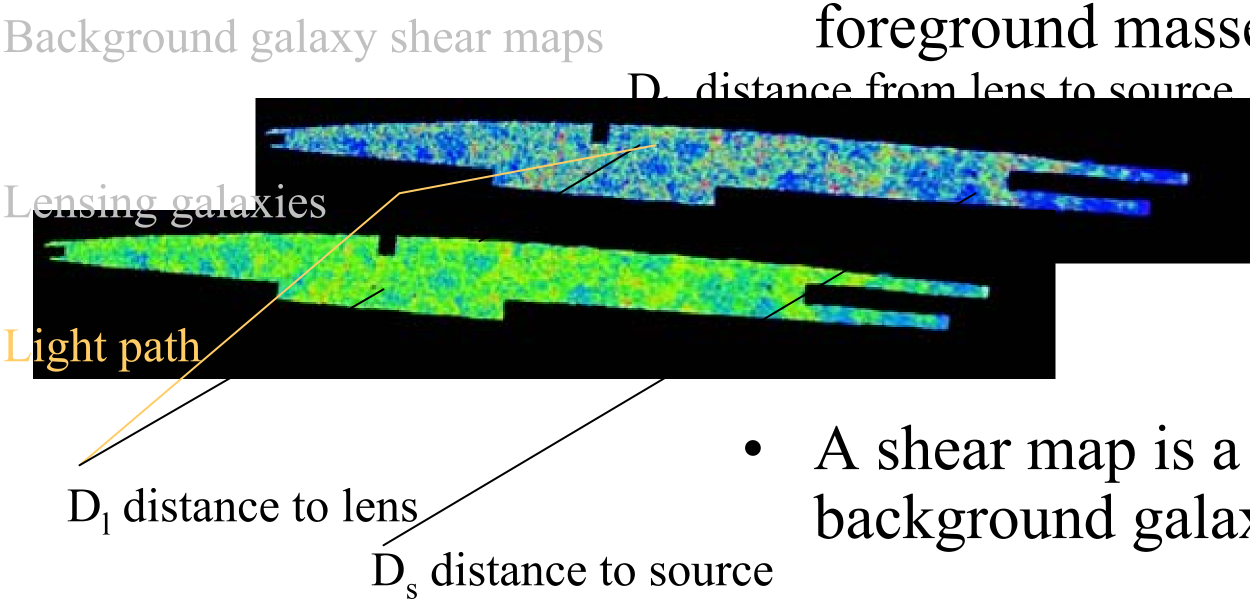
- The distribution of galaxy positions on the sky reflects the initial positions of the mass
- Maps of galaxy positions are broken up in photometric redshift bins
- The spatial power spectrum is computed and compared with the CMB fiducial power spectrum.
- The peak and the baryon oscillations provide standard rulers.
- DES will
  - Image 5000 sq-degrees
  - Photo-z accuracy of $\delta z < 0.1$ to $z = 1$
  - 300 million galaxies



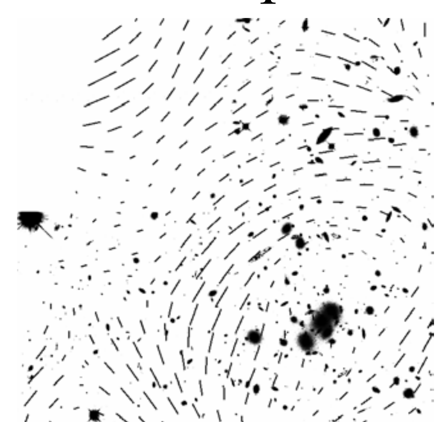


Weak Lensing

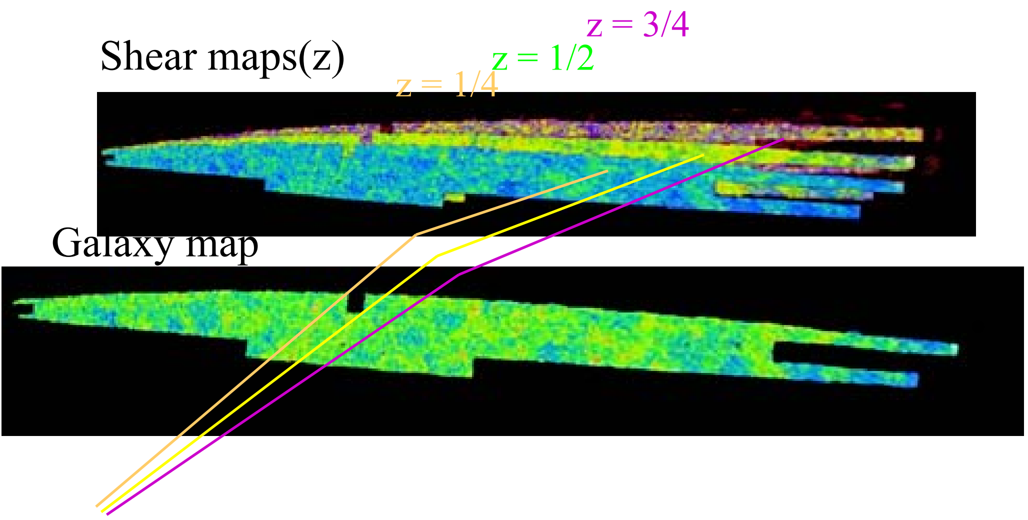
- Weak lensing is the statistical measurement of shear due to foreground masses



- A shear map is a map of the shapes of background galaxies

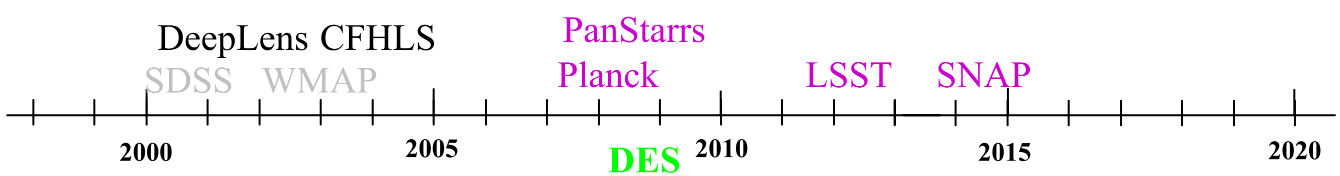


Weak Lensing

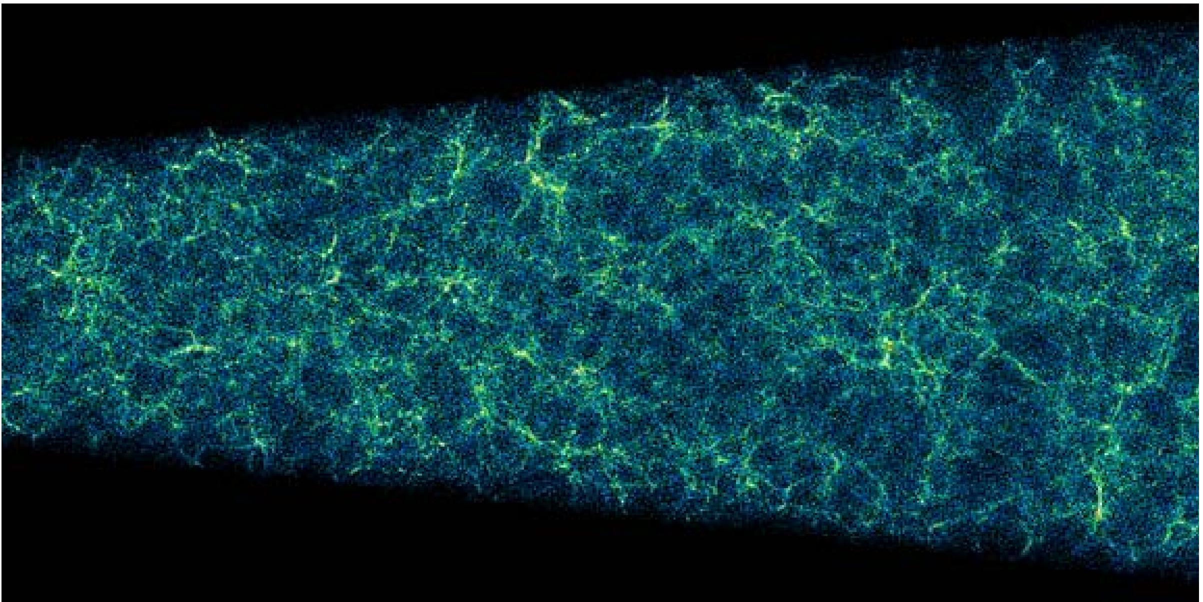


- The strength of weak lensing by the same foreground galaxies varies with the distance to the background galaxies.
  - Measure amplitude of shear vs. z
  - shear-galaxy correlations
  - shear-shear correlations

DES will
  - Image 5000 sq-degrees
  - Photo-z accuracy of $\delta z < 0.1$ to $z = 1$
  - 10-20 galaxies/sq-arcminute



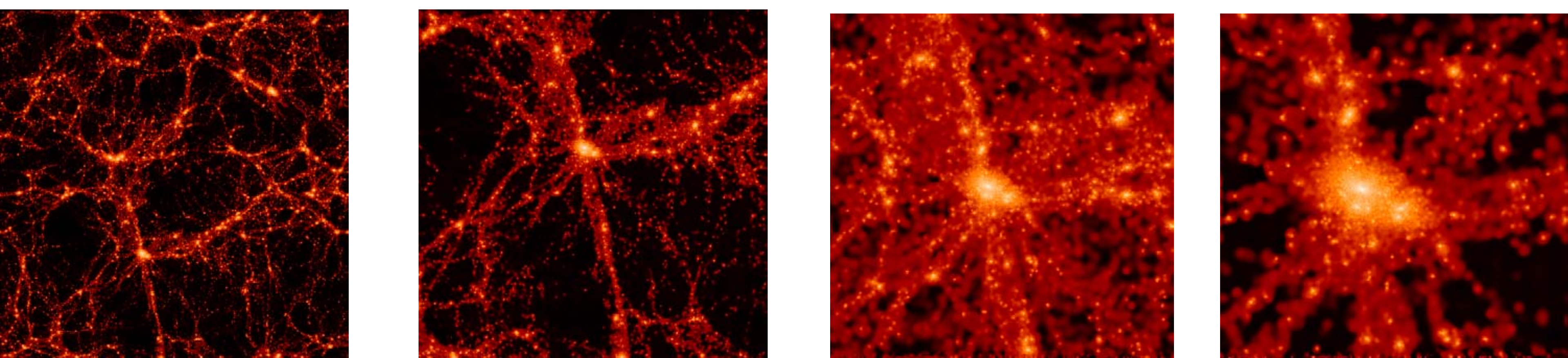
Peaks in the Density Field



- Clusters of galaxies are peaks of the density field.
- Dark energy influences the number and distribution of clusters and how they evolve with time.

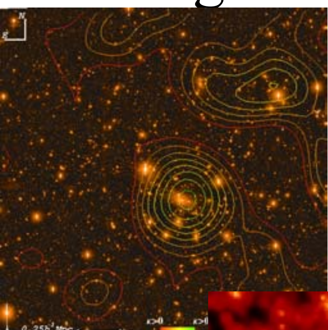
← 16 Mpc →

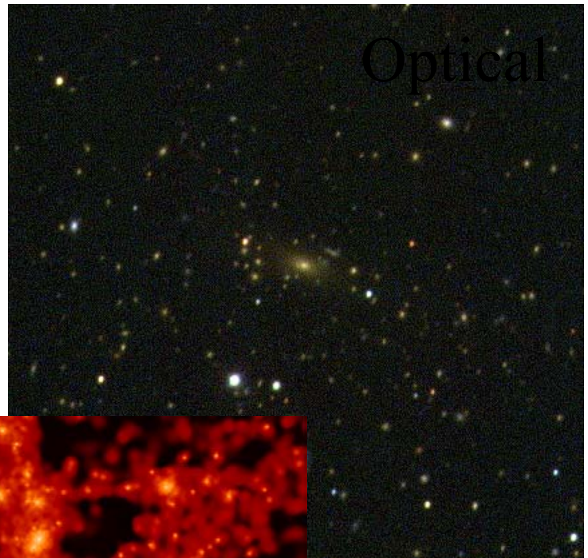
← 2 Mpc →

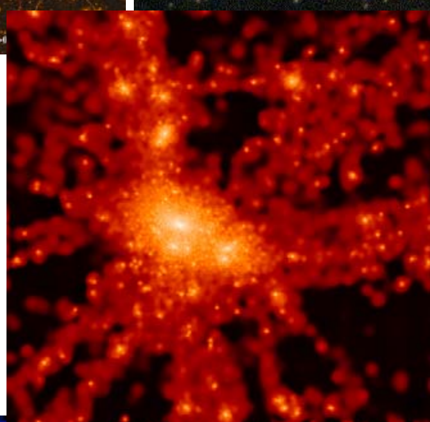


Cluster Masses

Lensing

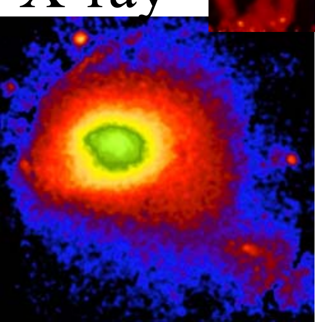




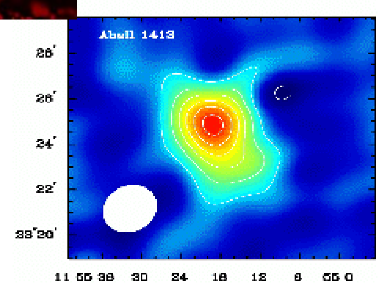


Mass

X-ray

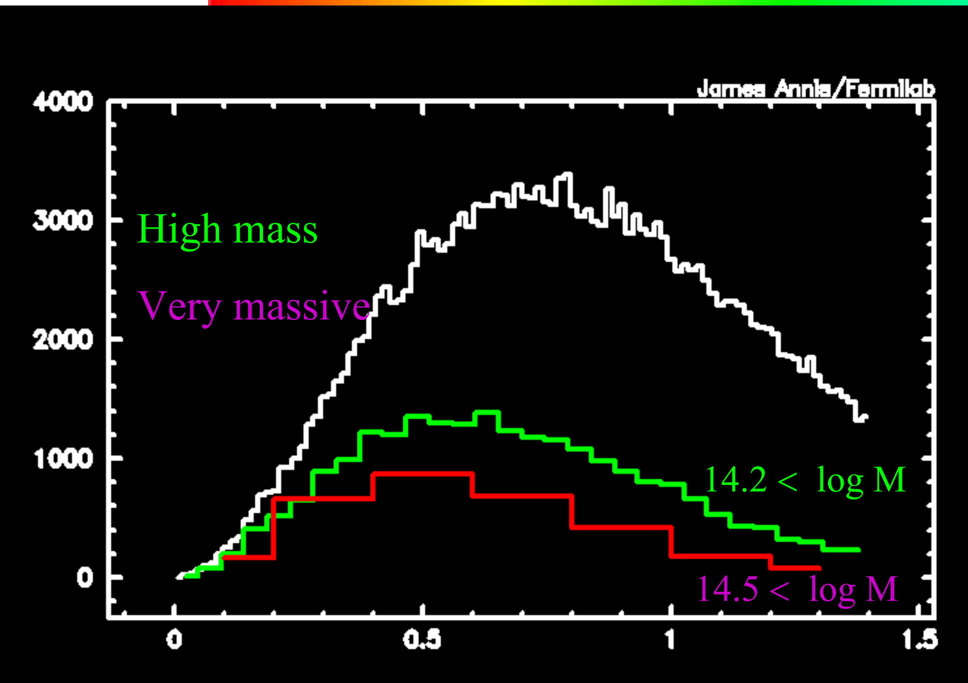


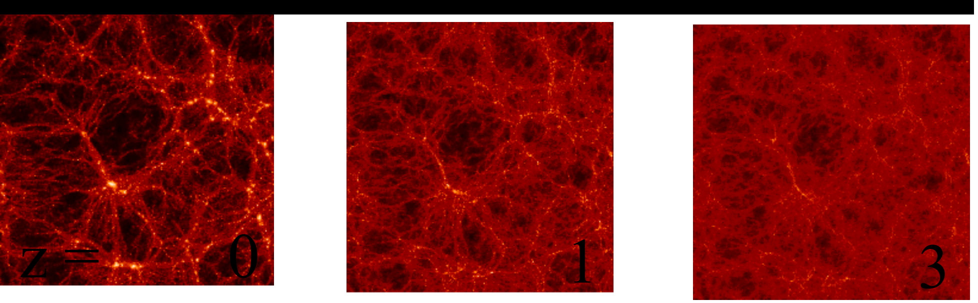
SZ



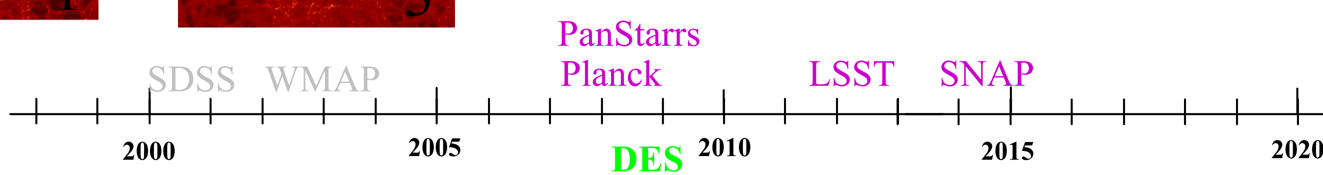
- Our mass estimators
  - Galaxy count/luminosity
  - Weak lensing
  - Sunyaev-Zeldovich
    - The South Pole Telescope project of J. Carlstrom et al.
    - DES and SPT cover the same area of sky
- Self calibration
  - Mass function shape allows independent checks
  - Angular power spectrum of clusters
  - Allows an approach at systematic error reduction

Cluster Counting





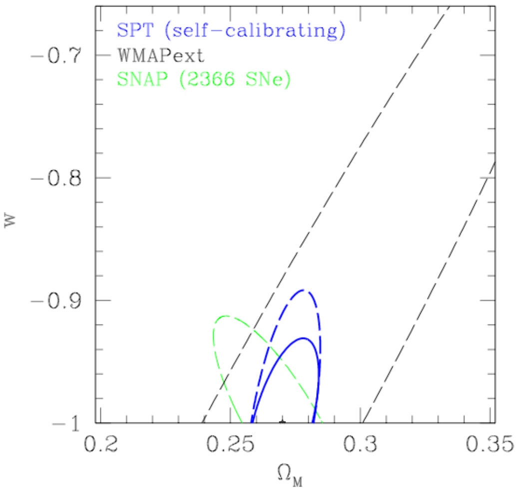
- Locate peaks in the density field using cluster finders
  - Red sequence methods
  - SZ peaks
- DES will
  - Image 5000 sq-degrees
  - Photo-z accuracy $\delta z = 0.01$ to $z = 1$
  - 20,000 massive clusters
  - 200,000 groups and clusters



We aim at ~5% precision on Dark Energy

Cluster Counting

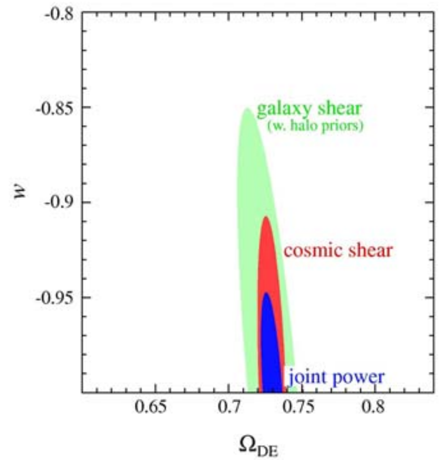
w



Ω_M

Weak Lensing

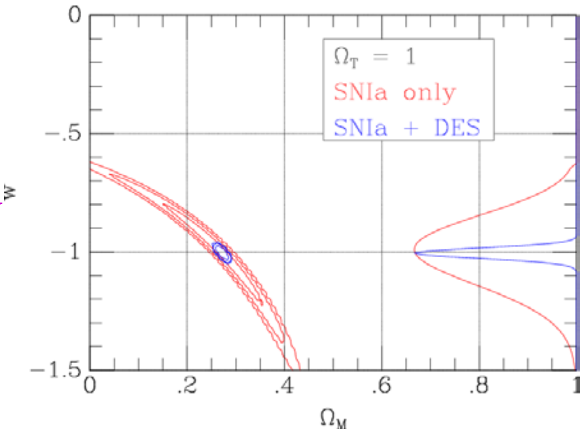
w



Ω_{DE}

Supernova

w



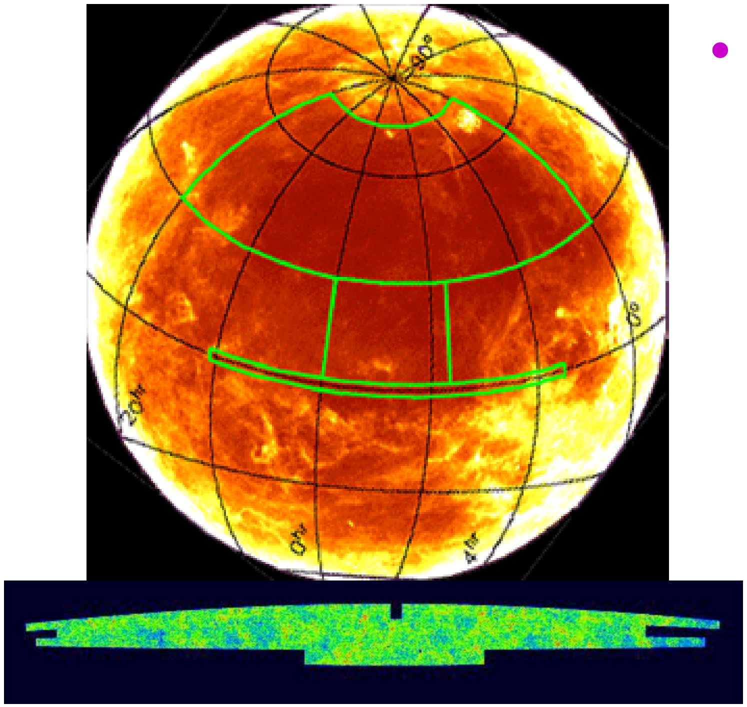
Ω_M

δ w ~ 5% and $\delta\ \Omega_{DE}$ ~ 3%

The Planck satellite will provide tighter input CMB measurements, and the constraints will improve slightly.

Joint constraints on w and w_a are promising: initial results suggest $\delta w_a \sim 0.5$.

The Dark Energy Survey



5000 sq-degrees

Overlapping SPT SZ survey

4 colors for photometric redshifts

300 million galaxies

- We propose the Dark Energy Survey
  - **Construct a 500 Megapixel camera**
  - Use CTIO 4m to image 5000 sq-degrees
  - Map the cosmological density field to z=1
  - Make precision measurements of the effects of Dark Energy on cosmological expansion:
    - Cluster counting
    - Weak lensing
    - Galaxy clustering
    - Supernovae

Backup slides

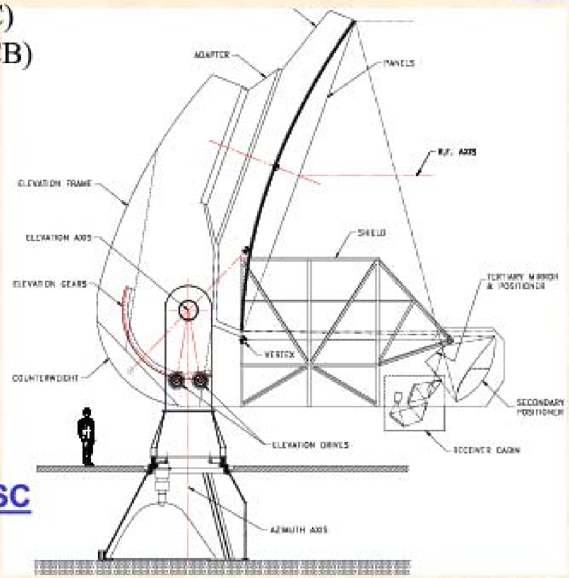
South Pole Telescope

8m (10m) South Pole Telescope (SPT) and 1000 element bolometer array

PEOPLE

Carlstrom (UC)
Holzapfel (UCB)
Lee (UCB)
Leitch (UC)
Meyer (UC)
Mohr (UIUC)
Padin (UC)
Pryke (UC)
Ruhl (UCSB)
Spieler (UCB)
Stark (CfA)

NSF – OPP
Raytheon PSC
CfCP



Low noise, precision telescope

- 20 um rms surface over 8m
- 1 arcsecond pointing
- 1.25 arcminute at 2 mm
- ‘chop’ entire telescope
- 3 levels of shielding
  - 1 m radius on primary
    8 m precision surface
  - inner moving shields
  - outer fixed shields

SZE and CMB Anisotropy

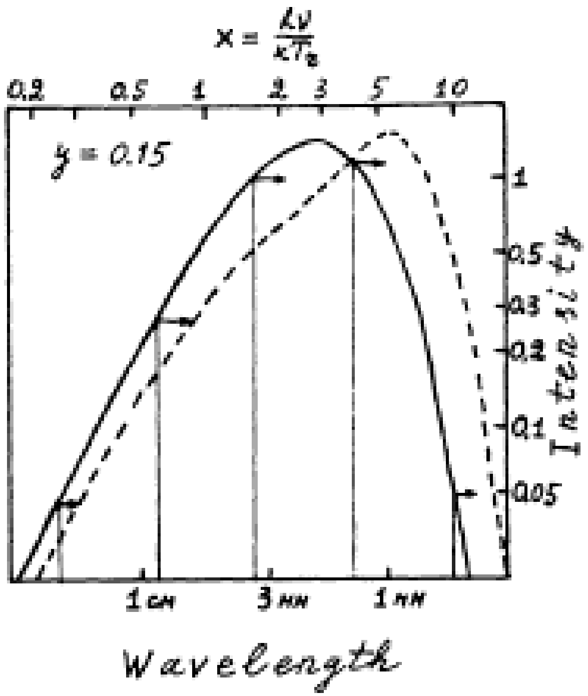
- at least two bands
  150 & ~250 GHz
- 4000 sq deg SZE survey
- deep CMB anisotropy fields
- deep CMB Polarization fields

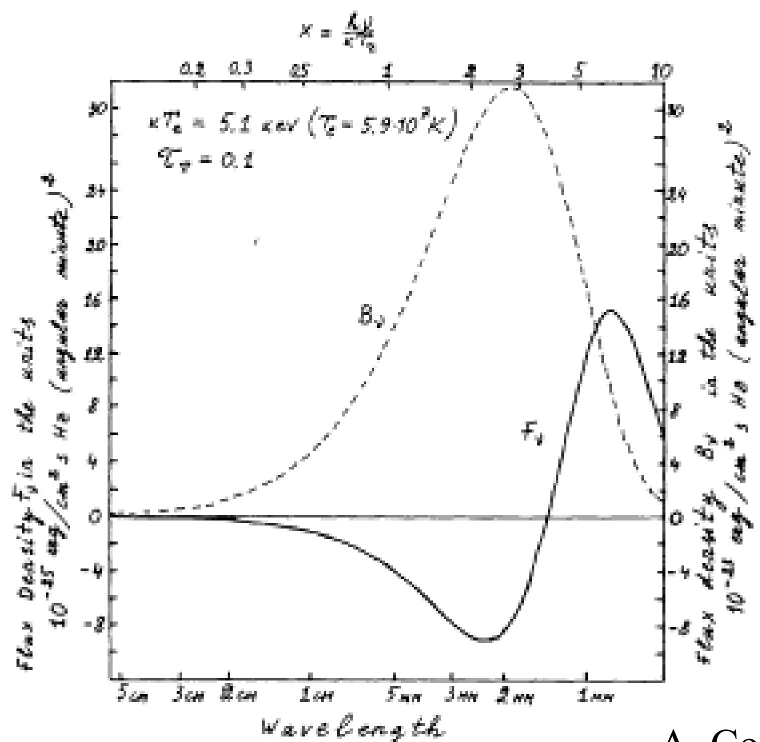
NSF-OPP Funded & scheduled for Nov 2006 deployment

Sunyaev-Zeldovich Effect

⇒ *Scattering moves photons from low frequencies (RJ part of the frequency spectrum) to high frequencies (Wien regime)*

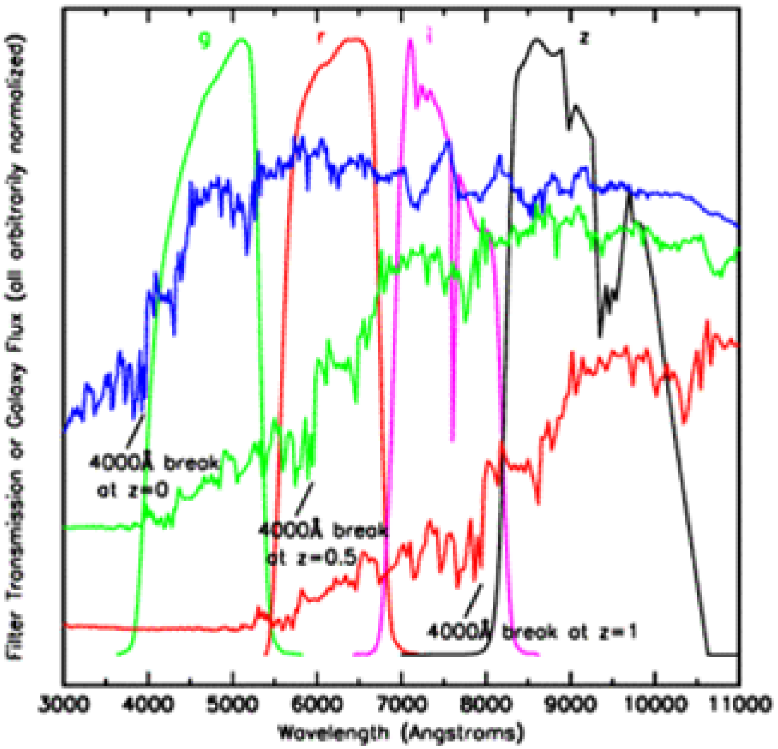
In the language of
Sunyaev-Zel'dovich (1980):

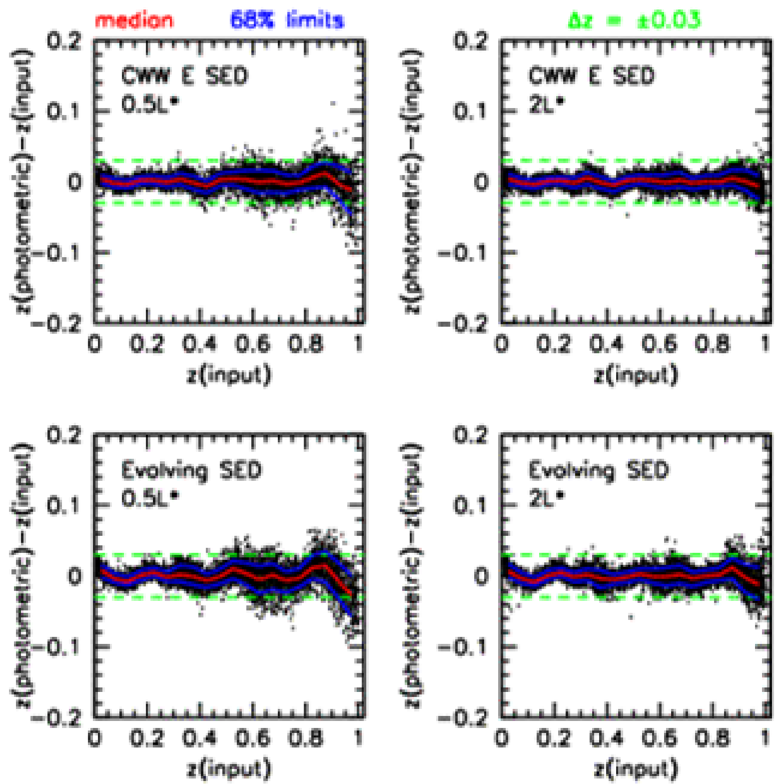




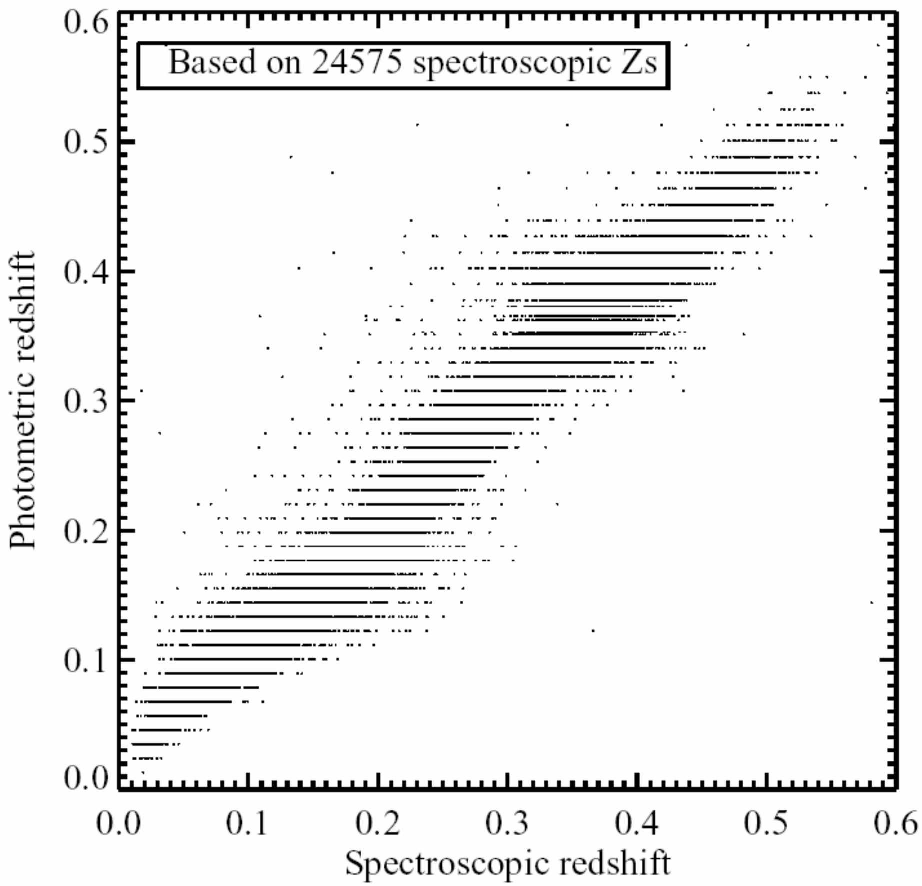
A. Cooray

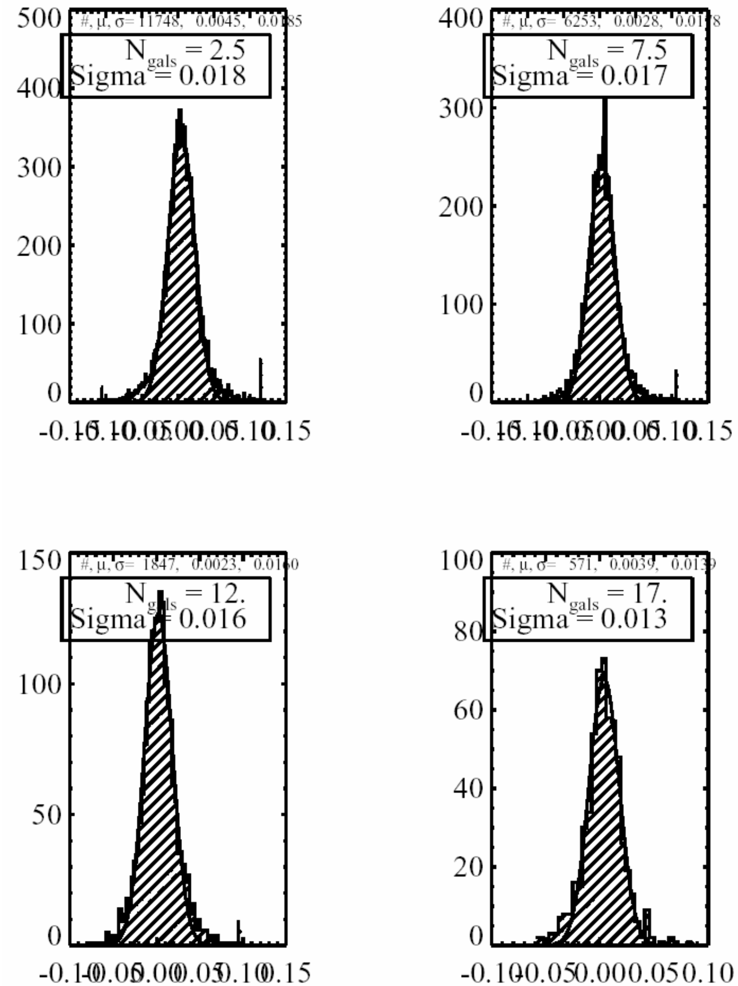
Photometric Redshifts I





MaxBcg Cluster Photometric Redshifts





MaxBcg Galaxy Cluster Finding